COLUMBIUM ALLOY EXTRUSION PROGRAM

PHASE V: TUBING PROGRAM
INTERIM REPORT VIII
15 JANUARY 1963 - 15 APRIL 1963

BASIC INDUSTRIES BRANCH
METALLURGICAL PROCESSING BRANCH
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

ASD PROJECT NO. 7-775

The final tube blank extrusion campaign is described, and the tube reducing program for extruded tube blanks of B-66 (Cb-5Mo-5V-1Zr) and D-43, previously designated X-110, (Cb-10W-1Zr-0.1C) is discussed. The processing is nearing completion on part of the D-43 tubes. The cracking of the B-66 during the first tube reduction has persisted.

(Prepared under Contract AF33(600)-40700 by E. I. du Pont de Nemours and Company, Inc., Baltimore, Maryland, E. V. Peterson)

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Copies of ASD Technical Reports should not be returned to the ASD Manufacturing Technology Laboratory unless return is required by security considerations, contractual obligations, or notice on a specified document.

FOREWORD

This Interim Technical Documentary Progress Report covers the work performed under Contract AF33(600)-40700 from 15 January 1963 to 15 April 1963. It is published for technical information only and does not necessarily represent the recommendations, conclusions or approval of the Air Force.

This contract with E. I. du Pont de Nemours & Company, Inc., Baltimore, Maryland was initiated under Manufacturing Methods Project 7-775, "Columbium and Columbium Alloy Extrusion Program". It is being accomplished under the technical direction of Mr. T. S. Felker of the Manufacturing Technology Laboratory, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio.

Mr. E. V. Peterson, Development Engineer, Metals Center, Baltimore, is the engineer directly responsible for the work. Others who cooperated in the development program were: Mr. J. S. Clark, Technical Supervisor, and Mr. J. A. Crane, Laboratory Engineer.

Wolverine Tube Division of Calumet Hecla, Inc., is the subcontractor to E. I. du Pont de Nemours & Company, Inc., for the tube reduction development program. Mr. J. C. Huber is the engineer directly responsible for the work at Wolverine. Mr. F. C. Eddens, Manager, Special Metals Department, and Mr. L. B. Moorman, Project Metallurgist, also contributed to this program.

Your comments are solicited on the potential utilization of the information contained herein as applied to your present or future production programs. Suggestions concerning additional Manufacturing Methods development required on this or other subjects will be appreciated.

PUBLICATION REVIEW

Approved by: W S Wartel
W. S. Wartel
Technical Superintendent
Metal Products

Approved by: E M Mahla
E. M. Mahla
Technical Assistant
to Director
Metal Products

James S Clark
J. S. Clark
Technical Supervisor
Metal Products

INTERIM TECHNICAL PROGRESS REPORT NO. 7-775 (VIII)
15 JANUARY 1963 - 15 APRIL 1963

COLUMBIUM AND COLUMBIUM ALLOY EXTRUSION PROGRAM
TUBING PROGRAM

ABSTRACT

The extrusion of three B-66 (Cb-5Mo-5V-1Zr) billets completed the extrusion part of the program.

The processing of D-43, previously designated X-110, (Cb-10W-1Zr-0.1C) tube blanks was continued in the third three-month period of Phase V. Some of the blanks have been processed through four reductions with 2600°F anneals after the first and third reduction. The outside surfaces are good. The inside surfaces have been improved by in-process conditioning, but a few defects still remain.

Attempts to make first reductions on the B-66 (Cb-5Mo-5V-1Zr) blanks resulted in cracking. The conditions that appear necessary for tube reducing the B-66, namely warm working, are beyond the scope of the present contract. Consequently, the work with B-66 was suspended, except for one piece of material which survived the first tube reduction.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

This report summarizes the results of the work performed during the third three-month period of Phase V of the "Columbium Alloy Extrusion Program". The first two three-month periods of Phase V have been summarized in (1) and (2)[1].

The goal of Phase V is to produce three sizes of tubing of the columbium alloys B-66 and D-43 as follows:

1/2" O.D. x 0.062" wall (40% by weight)
3/8" O.D. x 0.062" wall (40% by weight)
1/4" O.D. x 0.018" wall (20% by weight)

The processing steps are -

1) double vacuum arc melt 8" diameter ingots
2) extrude to 4" rounds
3) machine hollow billets and re-extrude to 1.750" O.D. x 0.30" and 0.25" wall tube blanks
4) tube reduce to finished tubing

Wolverine Tube Company, Allen Park, Michigan, is subcontractor to Du Pont for the tube reduction program. Wolverine and Du Pont have engaged in a cooperative program to determine a satisfactory reduction-anneal schedule for B-66 and D-43 tubes.

---

1 Numbers in parentheses refer to the Bibliography at the end of the report.

II. SUMMARY OF PROGRESS

The final three B-66 tube blank extrusions in this program were performed during the reporting period. Two tube blanks with fair to poor surfaces were obtained. One extrusion stalled the press. The tube blanks were successfully straightened at a temperature of 500°F in an hydraulic press.

Continued efforts to make the first reduction on B-66 tube blanks resulted in cracking. However, one blank survived the first pass with one major radial crack. After a meeting with Westinghouse and Wolverine Tube personnel, it was concluded that the conditions desired for processing of B-66, namely working at approximately 500°F, were beyond the scope of work covered by the present contract. Funds were not available on this contract to pursue the warm working. Work on B-66 was suspended, except for the one piece which took the first reduction. This piece was annealed at 2600°F after the first reduction and subsequently given the second reduction to 1.062" O.D. x 0.147" wall. No additional cracking occurred, but the I.D. surface was extensively pitted.

The processing of D-43 has progressed satisfactorily with the major problem being internal conditioning to remove surface defects. The general surface condition of the I.D. has been improved by additional reductions and conditioning between reductions, but a few defects still remain.

Six D-43 tube blanks have had two reductions (to 1.062" O.D. x .100" and .147" wall), four blanks have had three reductions (to .815" O.D. x .065" wall), and two blanks have had four reductions (to 0.625" O.D. x 0.073" wall). Anneals at 2600°F were given after the first and third reductions, and the blanks were extensively conditioned on the I.D. after the first, second, and third reductions.

Minor end splitting on some blanks was cropped before further reduction.

III. TECHNICAL DATA

A. TUBE BLANK EXTRUSIONS

Three B-66 billets which had stalled in the third series of extrusions, as indicated in Interim Report VII, were remachined. An attempt was made to salvage this material by extruding according to the best extrusion practices as described in Interim Report VI and VII. The dies and mandrels were the same as described in Interim Report VII. Briefly, the dies were the 90° cone type. The working surfaces of both the dies and mandrels were zirconium-oxide coated. The finished coatings, after grinding, were approximately 0.030" thick. The extrusion size would allow approximately 0.050" of material for "clean-up" on both the inside and outside surfaces of the tube blank (tube blank size was 1.750" O.D. x 0.300" wall). The billets were machined as shown in Figure 1.

The extrusion procedure was as follows:

1. Heat billet in induction heater under protective atmosphere, at rate of 150-200°F/minute. Measure temperature by optical pyrometer. Soak 5 minutes.
2. Lubricate liner with mixture of MoS_2 and "Oildag".[1]
3. Insert die and mandrel (preheated in 750°F oven for 1/2 hour) in press.
4. Transfer billet from heater to press in less than 35 seconds. Roll heated billet over powdered glass on glassing table in transfer; apply powdered glass to bore manually.

[1] Proprietary lubricant manufactured by Acheson Colloids Company.

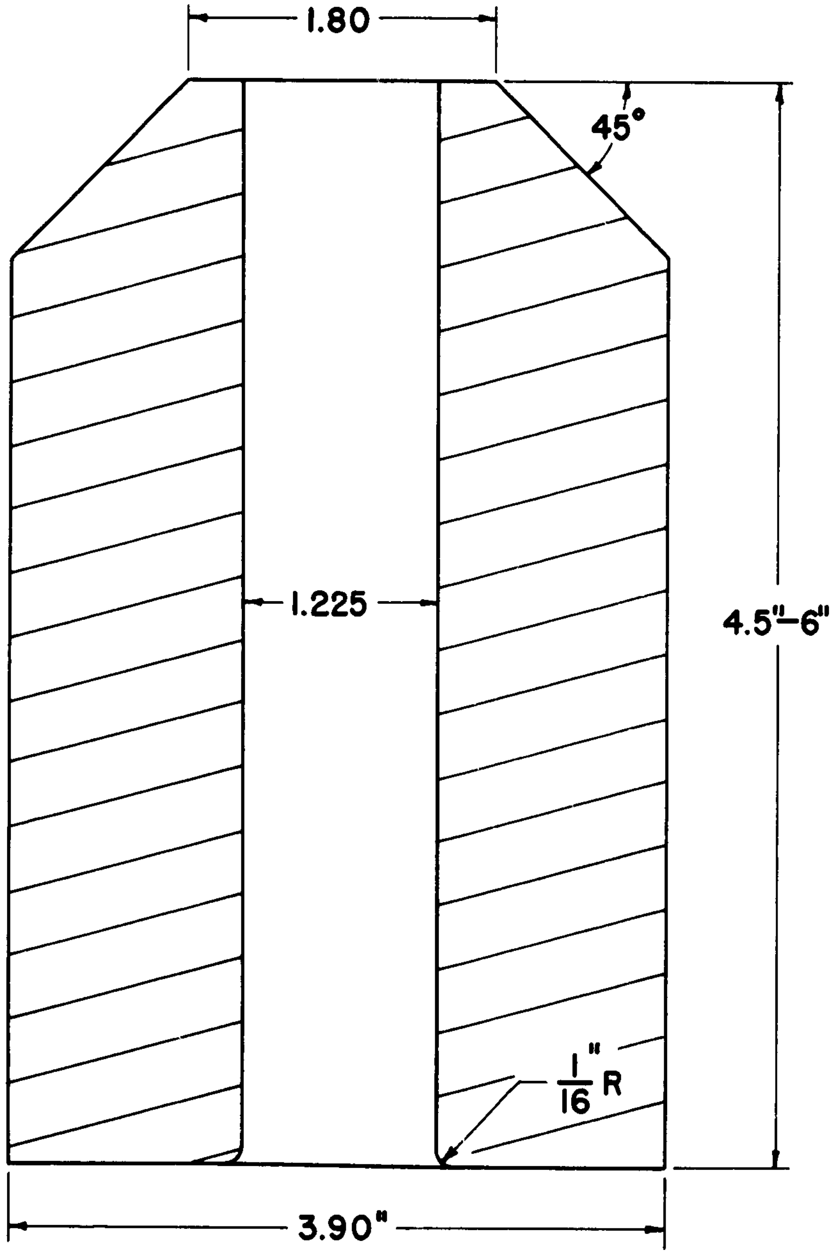

FIGURE 1

BILLET DESIGN FOR TUBE BLANK EXTRUSIONS

5. Place two 1" thick graphite pads heated to 2200°F directly behind billet. Place a 2" thick copper follower block behind graphite.

6. Extrude at ram speed of approximately 5"/second.

The results of the extrusions are shown in Table 1. One extrusion stalled the press. One of the other two extrusions produced a fairly good tube blank, but the other one was too rough on both I.D. and O.D. surfaces to warrant further processing.

TABLE 1

B-66 TUBE BLANK EXTRUSIONS
(in order of performance)

Billet	Die Type	Extrusion Ratio	Billet Temp °F	Extrusion Pressure, ksi B.T.	Extrusion Pressure, ksi Running	Results
B-66-277-03	Cone	7.5:1	2940	190	--	Stalled
B-66-279-04	Cone	7.5:1	3100	190	144-170	O.D. surfaces fair I.D. surfaces fair
B-66-347-02	Cone	7.5:1	3080	190	143-160	O.D. surfaces poor I.D. surfaces good over first half of extrusion, and poor over last half

B. STRAIGHTENING TUBE BLANKS

Previous attempts to straighten B-66 and D-43 tube blanks, (room temperature), in both a roller straightener and in a gag press have resulted in cracking of the blanks(2). Several blanks of both alloys, as-extruded and deep-pickled, were successfully straightened in a gag press after preheating the blanks for approximately 1/2 hour in an oven at 550°F. Each blank was taken immediately to the press from the oven and worked during an approximate one-minute period. No breaking occurred and no cracking was evident. The degree of straightness obtained in the gag press was variable and not accomplished with the degree of precision associated with roller straightening. However, this operation demonstrated that tube blanks of both alloys, when given the preheat treatment, could be straightened sufficiently for tube reduction.

C. TUBE REDUCTION

Wolverine Tube, Allen Park, Michigan, is the subcontractor who is performing the tube reductions in a cooperative program with Du Pont. The process schedules, set up by Wolverine and agreed to by Du Pont, are shown below as Schedule No. 1 (1/2" and 3/8" O.D. tubing) and Schedule No. 2 (1/4" O.D. tubing).

At the time Interim Report VII was issued, ten tube blanks had been put through the first reduction; seven of these were D-43 (X-110), and three were B-66. All three B-66 blanks cracked radially, two of them after careful hand conditioning and repickling. The D-43 blanks were reduced successfully. All blanks (D-43 and B-66) were in the annealed condition, and both materials were comparable with respect to surface condition and size and type of defects present(2).

During the third quarter of Phase V, an additional B-66 blank, annealed and extensively conditioned to remove all visible defects, cracked during the first reduction. Three more B-66 blanks in the "as-extruded" condition were given the first reduction. Two of these failed to take the reduction. The third was reduced, with one large radial crack evident.

Because of the general lack of success in making the first tube reductions on B-66, work on B-66 was halted to permit study of the problem.

Room temperatuɪe bend tests were made on machined specimens of B-66 tube blanks in order to get an indication of room temperature ductility. The specimens were approximately 1/8" thick x 5/16" wide x 2" long, and were taken longitudinally

PROCESS SCHEDULE NO. 1

Tube Reduction to 1/2" and 3/8" O.D. Tubing

Finish target sizes: .500" ± .005" O.D. x .060" ± 10% wall (40%)[1]

.375" ± .005" O.D. x .060" ± 10% wall (40%)[1]

Starting material: 1.750" O.D. x .300" wall

	Operation	Size	% Wall Reduction	% Area Reduction
1.	Inspect	1.750" ODx.300" wall	-	-
2.	Tube reduce	1.375" ODx.210" wall	30	43.8
3.	Inspect			
4.	Anneal			
5.	Salvage; inspect			
6.	Tube reduce	1.062" ODx.147" wall	30	44.9
7.	Inspect			
8.	Salvage; inspect			
9.	Tube reduce	.812" ODx.103" wall	30	45.9
10.	Inspect			
11.	Anneal			
12.	Salvage; inspect			
13.	Tube reduce	.625" ODx.073" wall	30	45.0
14.	Inspect			
15.	Salvage; inspect			
16.	Tube reduce			
		half to .500" ODx.060" wall	30	34.1
		half to .375" ODx.060" wall	30	53.2
17.	Inspect			
18.	Anneal			
19.	Salvage			
20.	Final inspection			

[1] Percentage based on total material supplied by Du Pont

PROCESS SCHEDULE NO. 2

Tube Reduction to 1/4" O.D. Tubing

Finish target size: .250" ± .005" O.D. x .015/.020" wall (20%)[1]

Starting material: 1.750" O.D. x .250" wall

	Operation	Size	% Wall Reduction	% Area Reduction
1.	Inspect	1.750" ODx.250" wall	-	-
2.	Tube reduce	1.375" ODx.160" wall	35	47.5
3.	Inspect			
4.	Anneal			
5.	Salvage; inspect			
6.	Tube reduce	1.062" ODx.100" wall	35	50.8
7.	Inspect			
8.	Salvage; inspect			
9.	Tube reduce	.812" ODx.065" wall	35	49.5
10.	Inspect			
11.	Anneal			
12.	Salvage; inspect			
13.	Tube reduce	.625" ODx.038" wall	42	53.9
14.	Inspect			
15.	Salvage; inspect			
16.	Tube reduce	.500" ODx.022" wall	42	52.8
17.	Inspect			
18.	Anneal			
19.	Salvage; inspect			
20.	Tube reduce	.250" ODx.018" wall	18	60.6
21.	Inspect			
22.	Anneal			
23.	Salvage			
24.	Final inspection			

1 Percentage based on total material supplied by Du Pont

from the wall of the tube blank and centrally located within the wall thickness, Figure 2. The specimens were tested (1) as-extruded, (2) annealed at 2400°F for 1 hour, and (3) annealed at 2600°F for 1 hour. The tests were made without strain rate measurements on a slow acting hydraulic press. All specimens withstood a 90° 2T bend without any evidence of cracking. Further bending of the same specimens without physical restraint to a 180° and approximately 1/2T bend showed no cracking of any of the annealed specimens. Two of four "as-extruded" specimens broke just prior to completion of the 180° bend. This behavior indicated a high degree of ductility under slow bend conditions at room temperature.

A meeting was held with Westinghouse and Wolverine Tube to discuss the B-66 cracking problem. The results of the tube reducing attempts, the bend test results, and the Westinghouse experience with the alloy were discussed. It was concluded that the most favorable approach to the reduction of the B-66 tube blanks would be warm working (approximately 500°F). It was felt that the extruded B-66 was too strain rate sensitive at room temperature to readily permit making the first tube reduction under present conditions, and that its workability would be appreciably better at 500°F. Inasmuch as warm working is beyond the scope of the present contract, and in view of the small amount of usable B-66 tube blank stock remaining, and of the limited funds available, no further first reductions were made.

The one B-66 blank that did withstand the first reduction, with one large crack, was annealed at 2600°F, I.D.

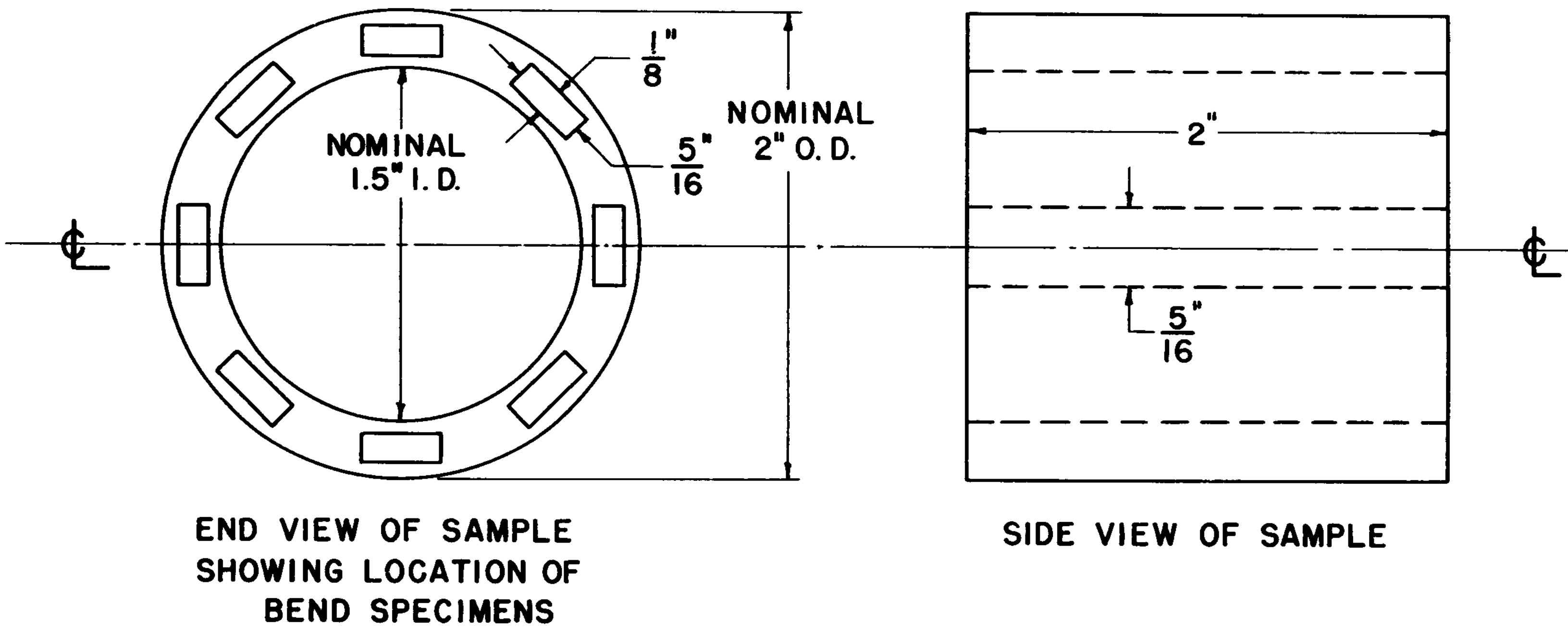

FIGURE 2

LOCATION OF BEND SPECIMENS IN TUBE BLANK SAMPLE conditioned, and second reduced to 1.062" O.D. x 0.147" wall. No additional cracking occurred, but the I.D. surfaces were extensively pitted. A length of about 24", which is in good condition, will be processed.

The reduction of the D-43 tube blanks has proceeded according to the processing schedules referred to above. As many as four reductions, with in-process anneals at 2600°F after the first and third reductions, have been made on some of the tube blanks. Limited end splitting has occurred, but was readily controlled by cropping. The major problem continues to be conditioning of residual extrusion defects from the inside surfaces. The defects have been reduced in size and number by rather extensive conditioning between tube reductions, but some remain.

A summary of the tube reducing results of B-66 and D-43 is given in Tables 2, 3, and 4.

TABLE 2

SUMMARY OF RESULTS OF FIRST TUBE REDUCTION

Identification	Base Tube Heat Treatment	Tube Reduced to Size	Tube Reducing Schedule No.	Tube Reducing Pass No.	Results
D-43-278-02B	Annealed at 2600°F	1.375"O.D.x.210'W	1	1st	I.D. Defects
D-43-280-01B	Annealed at 2600°F	1.375"O.D.x.210'W	1	1st	I.D. Roughness. End splitting
D-43-280-07B	Annealed at 2600°F	1.375"O.D.x.160'W	2	1st	I.D. Defects
D-43-346-01B	Annealed at 2600°F	1.375"O.D.x.160'W	2	1st	I.D. Defects
D-43-346-03B	Annealed at 2600°F	1.375"O.D.x.210'W	1	1st	I.D. Roughness
D-43-278-03F	Annealed at 2600°F	1.375"O.D.x.210'W	1	1st	Satisfactory
D-43-278-05	Annealed at 2600°F	1.375"O.D.x.210'W	1	1st	Satisfactory
D-43-280-03F	Annealed at 2600°F	1.375"O.D.x.210'W	1	1st	Satisfactory
D-43-280-04	Annealed at 2600°F	1.375"O.D.x.210'W	1	1st	I.D. Defects; some O.D. surface cracks
D-43-280-06F	Annealed at 2600°F	1.375"O.D.x.210'W	1	1st	Satisfactory
D-43-280-06B	Annealed at 2600°F	1.375"O.D.x.210'W	1	1st	O.D. Surface good; some I.D. pits
B-66-277-01F	Annealed at 2600°F	1.375"O.D.x.160'W	2	1st	Tube cracked

D-43-346-01B	Annealed at 2600°F	1.375"O.D.x.160"W	2	1st	I.D. Defects
D-43-346-03B	Annealed at 2600°F	1.375"O.D.x.210"W	1	1st	I.D. Roughness
D-43-278-03F	Annealed at 2600°F	1.375"O.D.x.210"W	1	1st	Satisfactory
D-43-278-05	Annealed at 2600°F	1.375"O.D.x.210"W	1	1st	Satisfactory
D-43-280-03F	Annealed at 2600°F	1.375"O.D.x.210"W	1	1st	Satisfactory
D-43-280-04	Annealed at 2600°F	1.375"O.D.x.210"W	1	1st	I.D. Defects; some O.D. surface cracks
D-43-280-06F	Annealed at 2600°F	1.375"O.D.x.210"W	1	1st	Satisfactory
D-43-280-06B	Annealed at 2600°F	1.375"O.D.x.210"W	1	1st	O.D. Surface good; some I.D. pits
B-66-277-01F	Annealed at 2600°F	1.375"O.D.x.160"W	2	1st	Tube cracked
B-66-277-01B	Annealed at 2600°F	1.375"O.D.x.160"W	2	1st	Tube Cracked
B-66-279-01F	Annealed at 2600°F	1.375"O.D.x.210"W	1	1st	Tube broke in tube reducer
B-66-279-01B	Annealed at 2600°F and extensively conditioned	1.375"O.D.x.210"W	1	1st	Tube broke in tube reducer and I.D. galling occurred
B-66-277-05B	As Extruded	1.375"O.D.x.210"W	1	1st	Tube broke in tube reducer
B-66-279-02F	As Extruded	1.375"O.D.x.210"W	1	1st	Good. I.D. pits; O.D. galling; one radial crack
B-66-347-04B	As Extruded	1.375"O.D.x.210"W	1	1st	Broke in tube reducer

TABLE 3

SUMMARY OF RESULTS OF SECOND TUBE REDUCTION

Identification	Starting Condition	Tube Reduced to Size	Tube Reducing Schedule No.	Tube Reducing Pass No.	Results
D-43-278-02B	Annealed at 2600°F	1.062"O.D.x0.147"W	1	2nd	Good. I.D. honing required
D-43-280-01B	Annealed at 2600°F	1.062"O.D.x0.147"W	1	2nd	Good. I.D. honing required
D-43-280-07B	Annealed at 2600°F	1.062"O.D.x0.100"W	2	2nd	Very good. Isolated defects
D-43-346-01B	Annealed at 2600°F	1.062"O.D.x0.100"W	2	2nd	Very good. Isolated defects
D-43-346-03B	Annealed at 2600°F	1.062"O.D.x0.147"W	1	2nd	Good. I.D. honing required
D-43-278-05	Annealed at 2600°F	1.062"O.D.x0.147"W	1	2nd	Good
D-43-280-04	Annealed at 2600°F	1.062"O.D.x0.147"W	1	2nd	I.D. honing required
D-43-280-06F	Annealed at 2600°F	1.062"O.D.x0.147"W	1	2nd	End cracks 1-1/8" long
D-43-280-06B	Annealed at 2600°F	1.062"O.D.x0.147"W	1	2nd	Good. Isolated defects
D-43-278-03F	Annealed at 2600°F	1.062"O.D.x0.147"W	1	2nd	Light O.D. pick-up. Isolated defects
D-43-280-03F	Annealed at 2600°F	1.062"O.D.x0.147"W	1	2nd	I.D. defects. Honing required
B-66-279-02F	Annealed at 2600°F	1.062"O.D.x0.147"W	1	2nd	Extensive I.D. defects over part of tube

TABLE 4

SUMMARY OF RESULTS OF THIRD TUBE REDUCTION

Identification	Starting Condition	Tube Reduced to Size	Tube Reducing Schedule No.	Tube Reducing Pass No.	Results
D-43-278-05	As Tube Reduced thru 2nd pass	.812"O.D.x0.103"W	1	3rd	Good
D-43-280-04	As Tube Reduced thru 2nd pass	.812"O.D.x0.103"W	1	3rd	I.D. pick-up. Honing required
D-43-280-06F	As Tube Reduced thru 2nd pass	.812"O.D.x0.103"W	1	3rd	End splits 2" long
D-43-280-06B	As Tube Reduced thru 2nd pass	.812"O.D.x0.103"W	1	3rd	End splits 1" long
D-43-278-03F	As Tube Reduced thru 2nd pass	.812"O.D.x0.103"W	1	3rd	End splits and I.D. pits. Honing required
D-43-280-03F	As Tube Reduced thru 2nd pass	.812"O.D.x0.103"W	1	3rd	Deep I.D. defects

TABLE 5

SUMMARY OF RESULTS OF FOURTH TUBE REDUCTION

Identification	Starting Condition	Tube Reduced to Size	Tube Reducing Schedule No.	Tube Reducing Pass No.	Results
D-43-280-06F	Annealed at 2600°F	.625"O.D.x.073"W	1	4th	Very good
D-43-280-06B	Annealed at 2600°F	.625"O.D.x.073"W	1	4th	Very good. Slight I.D. pick-up at one end

IV. FUTURE PROGRAM

A. TUBE REDUCTION

The tube reduction of D-43 will be continued as indicated on the Process Schedules Nos. 1 and 2.

Group I, now in process in the fourth reduction, will be given the fifth reduction to final size prior to the final anneal.

Group II, now ready for the third reduction, will be given the third reduction, annealed, then given the fourth reduction. At this point it is planned to alter the original processing schedule on part of the material to determine the effect of reduction-anneal schedule on final mechanical properties. Three pieces of tubing, one intended for each of the three final sizes, namely 0.500" O.D. x 0.060" wall, 0.375" O.D. x 0.060" wall, and 0.250" O.D. x 0.018" wall, will be given an additional anneal after the fourth tube reduction. The three pieces will then continue as per the original schedule. The balance of the material will follow the original schedule without an anneal between the fourth and fifth tube reductions.

B. FINAL INSPECTION AND EVALUATION

The final product will be given dimensional and surface inspections. Laboratory evaluation will include chemical analysis, photomicrographs, flare tests, and room temperature and 2200°F tensile tests.

A final report will be issued upon completion of the program.

V. ACKNOWLEDGEMENTS

The author wishes to acknowledge the contributions to this program by J. S. Clark for technical supervision, R. W. Felber for extrusion operations supervision, and J. A. Crane for metallography and mechanical testing.

Wolverine Tube is conducting the tube reduction and the in-process conditioning and inspection portion of the program. The valuable contributions of personnel of that company are acknowledged, in particular those of J. C. Huber, the engineer in charge, F. C. Eddens, Manager, Special Metals Department, and L. B. Moorman, Project Metallurgist.

VI. BIBLIOGRAPHY

(1) J. S. Clark, "Tubing Program", Interim Report VI, ASD Project No. 7-775, Columbium Alloy Extrusion Program, Air Force Contract No. AF33(600)-40700, October 15, 1962.

(2) J. S. Clark, "Tubing Program", Interim Report VII, ASD Project No. 7-775, Columbium Alloy Extrusion Program, Air Force Contract No. AF33(600)-40700, January 15, 1963.

DISTRIBUTION LIST

	Number of Copies
Commanding General AMC Aeronautical Systems Center ATTN: LMBML-1 Wright-Patterson Air Force Base, Ohio	3 plus reproducible
Armed Services Technical Information Agency Document Service Center Arlington Hall Station Arlington 12, Virginia	10
Chief, Bureau of Naval Weapons Department of the Navy Washington 25, D. C.	2
Commanding General Wright Air Development Division ATTN: WWRCEP Wright-Patterson Air Force Base, Ohio	2
Commanding Officer Attn: Mr. S.V. Arnold, Associate Director Watertown Arsenal Laboratories Watertown 72, Massachusetts	2
Bureau of Naval Weapons Department of the Navy Attn: Mr. S.E. Samfilippo, AE 155 Washington 25, D. C.	1
U. S. Atomic Energy Commission Technical Information Services Extension Attn: Mr. Hugh Voress P. O. Box 62 Oak Ridge, Tennessee	1
National Academy of Science National Research Council Division of Engineering and Industrial Resources Attn: Mr. E. V. Bennett Washington 25, D. C.	1
Commander Air Research & Development Command Attn: RDTDEG, Mr. Kniffen Andrews Air Force Base Washington 25, D. C.	1

	Number of Copies
E. I. DuPont De Nemours & Company, Inc. Pigments Department ATTN: Dr. E. M. Mahla, Techanical Assistant to the Director Metal Products Wilmington 98, Delaware	1
Fansteel Metallurgical Corporation ATTN: Mr. A. B. Michael, Director Metallurgical Research 2200 Sheridan Road North Chicago, Illinois	1
The Garrett Corporation AiResearch Manufacturing Division 9851 Sepulveda Boulevard Los Angeles 45, California	1
General Electric Company Aircraft Gas Turbine Division ATTN: Mr. G. J. Wile, Engineering Manager Metallurgical Engineering Operations Large Jet Engine Dept., Bldg. 501 Cincinnati 15, Ohio	1
Gruman Aircraft Engineering Corporation Manufacturing Engineering ATTN: Mr. W. H. Hoffman, Vice President Plant 2 Bethpage, Long Island, New York	1
H. M. Harper Company ATTN: Mr. E. A. Channer, Vice President Sales Lehigh Avenue and Oakton Street Morton Grove, Illinois	1
Harvey Aluminum, Inc. ATTN: Mr. G. A. Moudry, Technical Director 19200 South Western Avenue Torrance, California	1
Jones & Laughlin Steel Corporation ATTN: Mr. Robert S. Orr, Commercial Research Librarian 3 Gateway Center Pittsburgh 30, Pennsylvania	1

	Number of Copies
Jet Propulsion Laboratory California Institute of Technology ATTN: Mr. I. E. Newlan 4800 Oak Grove Drive Pasadena 3, California	1
Canton Drop Forging & Manufacturing Company ATTN: Mr. Chandis Brauchler 2100 Wilett Avenue Canton, Ohio	1
Convair General Dynamics Corporation ATTN: Mr. Fred Monahan, Mgr., Mfg. Dev. & Process Spec's P. O. Box 1950 - Zone 190-00 San Diego 12, California	1
Crucible Steel Company of America ATTN: Dr. Walter Finley Director of Research P. O. Box 88 Pittsburgh 30, Pennsylvania	1
Curtiss-Wright Corporation Metals Processing Division 760 Northland Avenue Buffalo 15, New York	1
Curtiss-Wright Corporation Wright Aeronautical Division Wood-Ridge, New Jersey	1
Douglas Aircraft Company, Inc. ATTN: Mr. C. B. Perry, C-345 Plant Engineering Supervisor 3855 Lakewood Boulevard Long Beach 8, California	1
Douglas Aircraft Company, Inc. Santa Monica, California	1
Dow Chemical Company Metallurgical Laboratory ATTN: Dr. T. E. Leontis, Assistant to the Director Midland, Michigan	1

	Number of Copies
National Aeronautics & Space Administration Lewis Research Center ATTN: George Mandel, Chief, Library 2100 Brookpark Road Cleveland 25, Ohio	1
Allegheny Ludlum Steel Corporation ATTN: Extrusion Plant Watervliet, New York	1
Hubert J. Altwicker Lebanon, Ohio	1
Aluminum Company of America Alcoa Building ATTN: Mr. R. W. Andrews Pittsburgh, Pennsylvania	1
Armour Research Foundation of Illinois Institute of Technology Metals Research Department ATTN: Mr. Frank A. Crosley 3350 South Federal Street Chicago 16, Illinois	1
Avco Corporation Research & Advanced Development Division ATTN: Mr. John V. Erickson, Manager Contracts & Administrative Services 201 Lowell Street Wilmington, Massachusetts	1
Babcock & Wilcox Company ATTN: Mr. James Barrett Beaver Falls, Pennsylvania	1
Baldwin-Lima-Hamilton Corporation ATTN: Mr. Fred A. Fielder Philadelphia 42, Pennsylvania	1
Battelle Memorial Institute Defense Metals Information 505 King Avenue Columbus 1, Ohio	1
Boeing Airplane Company P. O. Box 3107 Seattle, Washington	1

	Number of Copies
Kaiser Aluminum & Chemical Corporation Dayton Sales Office 349 W. First Street Dayton, Ohio	1
Lockheed Aircraft Corporation Burbank, California	1
Lockheed Aircraft Corporation ATTN: Mr. Max Tatman Dept. 81-63 Sunnyvale, California	1
Magnthermic Corporation ATTN: Mr. J. A. Logan Youngstown, Ohio	1
The Martin Company Baltimore 3, Maryland	1
The Martin Company Denver Division ATTN: Mr. R. F. Breyer Materials Engineering Mail No. L-8 P. O. Box 179 Denver 1, Colorado	1
McDonnell Aircraft Corporation Lambert - St. Louis Municipal Airport ATTN: Mr. C. E. Zoller P. O. Box 516 St. Louis 3, Missouri	1
NORAIR Division Northrop Corporation ATTN: Mr. J. A. Van Hamersveld 1001 East Broadway Hawthorne, California	1
Nuclear Metals, Inc. ATTN: Mr. Klein, Vice President Concord, Massachusetts	1
Republic Aviation Corporation ATTN: Mr. A. Kastelowitz, Director of Manufacturing Research Farmingdale, Long Island, New York	1
Republic Steel Corporation Republic Research Center 6801 Breckville Road Cleveland 31, Ohio	1

	Number of Copies
Reynolds Metal Company ATTN: Mr. Stuart Smith 918 16th Street, N. W. Washington 6, D. C.	1
Rohr Aircraft Corporation ATTN: Mr. S. P. Jenkins, Chief Manufacturing Research P. O. Box 878 Chula Vista, California	1
Ryan Aeronautical Company ATTN: Mr. L. J. Hull, Chief Metallurgist Material & Process Laboratory Lindberg Field San Diego 12, California	1
Sandia Corporation ATTN: Mr. E. H. Mebs, Sec. 1621 Sandia Base Albuquerque, New Mexico	1
Sandia Corporation Livermore Laboratory ATTN: Mr. M. W. Mote, Jr. P. O. Box 969 Livermore, California	1
Solar Aircraft Company ATTN: Mr. F. M. West, Chief Librarian 2200 Pacific Avenue San Diego 12, California	1
Thompson-Ramo-Wooldridge Staff Research & Development Chemical & Metallurgical Department ATTN: Mr. A. S. Nemy 23555 Euclid Avenue Cleveland 17, Ohio	1
Chance-Vought Corporation Chance-Vought Aeronautics Division ATTN: Mr. G. A. Starr, Chief Applied Research & Development P. O. Box 5907 Dallas, Texas	1
United Aircraft Corporation Pratt & Whitney Aircraft Division East Hartford, Connecticut	1

	Number of Copies
United States Steel Corporation Products Development Division 525 William Penn Place Pittsburgh, Pennsylvania	1
Universal-Cyclops Steel Corporation Refractomet Division ATTN: Mr. P. C. Rossin, General Manager Bridgeville, Pennsylvania	1
Vanadium Corporation of America ATTN: Mr. C. N. Cosman Metallurgical Engineer Graybar Building 420 Lexington Avenue New York 17, New York	1
Wah Chang Corporation 233 Broadway New York, New York	1
Wyman-Gordon Company ATTN: Mr. Arnold Rustay, Technical Director Grafton Plant Worcester Street North Grafton, Massachusetts	1
Westinghouse Electric Corporation Bettis Atomic Power Division ATTN: Virginia Sternburg, Librarian P. O. Box 1468 Pittsburgh 30, Pennsylvania	1
Westinghouse Electric Corporation ATTN: Mr. L. M. Bianchi Technical Liaison Engineer P. O. Box 128 Blairsville, Pennsylvania	1
University of California Lawrence Radiation Laboratory ATTN: Mr. John W. Cox P. O. Box 808 Livermore, California	1
Kawecki Chemical Company ATTN: Mr. Edwin J. Bielecki Research Manager Boyertown, Pennsylvania	1

	Number of Copies
Allegheny Ludlum Steel Corporation Research Center ATTN: Mr. R. K. Pitler Chief Research Metallurgist High Temperature Alloys Brackenridge, Pennsylvania	1
Haynes Stellite Company Division of Union Carbide Corporation ATTN: Mr. F. S. Badger, Vice President Metallurgy Kokomo, Indiana	1
Wolverine Tube Division of Calumet & Hecla, Inc. ATTN: Mr. F. C. Eddens Manager, Special Metals New Products Division 17200 Southfield Road Allen Park, Michigan	1
Battelle Memorial Institute Metal Working Division ATTN: Mr. A. M. Sabroff Assistant Chief 505 King Avenue Columbus, Ohio	1
Stauffer Metals Company ATTN: Dr. Jack Hum 1201 South 47th Street Richmond, California	1
William L. Bruckart Metallurgical and Marketing Consultant 85 Inglewood Drive Pittsburgh 28, Pennsylvania	1
Reactive Metals, Inc. ATTN: Mr. George W. Cleveland Sales Engineer Niles, Ohio	1
AiResearch Manufacturing Company of Arizona ATTN: E. A. Kovacevich, Engineering 402 South 36th Street Phoenix, Arizona	1
Wah Chang Corporation ATTN: Mabel E. Russell, Librarian P. O. Box 366 Albany, Oregon	1

	Number of Copies
Feller Engineering Company ATTN: Mr. R. C. Zeile, President Empire Building Pittsburgh 22, Pennsylvania	1
Mr. George M. Adamson Metals & Ceramics Division Oak Ridge National Laboratory P. O. Box X Oak Ridge, Tennessee	1
FTD (TD-E2b) Wright-Patterson AFB Dayton, Ohio	1
National Aeronautics & Space Administration Lewis Laboratory ATTN: Mr. Raymond D. Gavert SEPC -10 X 10 S.W.T. Room 126 21000 Brookpark Road Cleveland 35, Ohio	1
Erie Foundry Company ATTN: Mr. J. E. Wilson General Sales Manager Erie 6, Pennsylvania	1
Mr. R. M. Mayfield Argonne National Laboratory 9700 South Cass Avenue Argonne, Illinois	1
The W. S. Tyler Company ATTN: Mr. Albert E. Reed Vice President 3615 Superior Avenue Cleveland 14, Ohio	1
General Electric Company Re-Entry Systems Department ATTN: Mr. R. G. Frank, Manager Physical Metallurgy SPPS-RSD-F-104 Cincinnati 15, Ohio	1

5Mo-5V-1Zr) and D-43, previously designated X-110, (Cb-10W-1Zr-0.1C) is discussed. The processing is nearing completion on part of the D-43 tubes. The cracking of the B-66 during the first tube reduction has persisted.	UNCLASSIFIED I. E.V.Peterson II. Contract AF33(600)-40700 III. Columbium and Columbium Alloy Extrusion Program	5Mo-5V-1Zr) and D-43, previously designated X-110, (Cb-10W-1Zr-0.1C) is discussed. The processing is nearing completion on part of the D-43 tubes. The cracking of the B-66 during the first tube reduction has persisted.	UNCLASSIFIED I. E.V.Peterson II. Contract AF33(600)-40700 III. Columbium and Columbium Alloy Extrusion Program
5Mo-5V-1Zr) and D-43, previously designated X-110, (Cb-10W-1Zr-0.1C) is discussed. The processing is nearing completion on part of the D-43 tubes. The cracking of the B-66 during the first tube reduction has persisted.	UNCLASSIFIED I. E.V.Peterson II. Contract AF33(600)-40700 III. Columbium and Columbium Alloy Extrusion Program	5Mo-5V-1Zr) and D-43, previously designated X-110, (Cb-10W-1Zr-0.1C) is discussed. The processing is nearing completion on part of the D-43 tubes. The cracking of the B-66 during the first tube reduction has persisted.	UNCLASSIFIED I. E.V.Peterson II. Contract AF33(600)-40700 III. Columbium and Columbium Alloy Extrusion Program